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Evaluation of the Performance of the LCC Windows for use in Laser Doppler Velocimetry

by

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FIGURES

SYMBOLS

DR1	Normalized data rate on LDV channel 1, axial velocity component
DR2	Normalized data rate on LDV channel 2, vertical velocity component
h	Channel height, and width, 10.0 ft (3048mm)
U	Axial velocity component, normalized by tunnel velocity
W	Vertical velocity component, normalized by tunnel velocity
x	Direction along tunnel axis, positive downstream
y	Horizontal direction perpendicular to tunnel axis, from tunnel centerline, positive starboard
z	Vertical direction, from tunnel centerline, positive up

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ABSTRACT

In order to get improved Laser Doppler Velocimeter (LDV) measurements in the LCC, two glass windows were acquired. The windows were specified to have surface and material quality suitable for quantitative LDV measurements, and much higher than that achievable with existing acrylic windows. Quantitative LDV measurements were taken of the flow in the empty channel both through the new glass window and through an acrylic window in order to compare window performance. The glass windows were found to show benefits for use with LDV in increased measurement accuracy, increased access to the flowfield, decreased time to obtain measurements, and increased capability to make spectral measurements.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

The external LDV system at the US Navy's Large Cavitation Channel (LCC) has been used for numerous tests since the channel's activation, and the reference LDV system has been used for the majority of the tests at the LCC. One particular weakness of these systems is that they must measure the flow in the channel through the viewing windows in the channel. These windows are constructed of 3.75" thick clear acrylic (plexiglass) which is suitable for qualitative viewing of the channel flow, but is questionable for use with quantitative LDV measurements. The existing acrylic windows have several limitations for use with LDV including: insufficient flatness of the window surfaces; non-homogeneity of the material which causes diffraction of the laser beams; and residual stresses in the material which cause the polarization of light passing through to change.

In order to get improved LDV measurements in the LCC, two glass windows were acquired from the Zygo Corporation. The windows were specified to have surface and material quality suitable for quantitative LDV measurements, and much higher than that achievable with acrylic. These windows were delivered, along with their stainless steel window frame, in late December 2007. The windows were first installed and tested in the LCC the week of 11 February, 2008. The empty channel was measured at this time both through one of the glass windows, as well as through an adjacent acrylic window for comparison. Some of the measurements duplicated measurements made in 2001 by Park et al.[1] to document the channel flow, and some measurements were made more specifically to document the window properties.

PROCEDURE

The glass windows were placed in Bay 2 of the LCC. The test section was empty. All measurements were made at a nominal speed of 9.0 m/s (impeller speed of 28.8 rpm) at 18 psia at the test top. Water temperature during the test was from 61 to 63°F.

Measurements were made through the glass window in bay 2 window 1. For comparison, an identical set of measurements was made through the best acrylic window (number 20) placed in bay 1 window 2. Simultaneous with these measurements, a reference velocity was measured in bay 1 window 1. The axial velocity component was measured with the green line from the argon laser, the vertical component was measured with the blue line from the laser, and the reference velocity used the violet line. The traversing probe had a 1600 mm focusing lens, while the stationary reference probe had an 800 mm focusing lens.

Even with a constant impeller speed, small fluctuations in the tunnel speed occur over time. In order to eliminate this effect, the speeds plotted here were normalized by the measured reference tunnel velocity at the time of the measurement. Data rates plotted here are all normalized by the reference data rate in order to compensate for fluctuations in the concentration of seed particles in the flow and fluctuations in the laser power.

Three types of measurement fields were acquired. First, a plane perpendicular to the tunnel axis, an x-plane, was measured at the center of each window. The x-plane was identical to that measured by Park et al. in 2001, and had 672 points in a grid that spanned 1550 mm across the tunnel and 1000 mm high. The x-plane was to show variation in performance across the channel. Second, a plane parallel to the window, a y-plane, was measured 600 mm from the tunnel centerline, on the side of the window. The y-plane was to show variation in performance across the window. Third, a line of points, a y-line, was measured at the center of the window from the window surface to 150mm inside the channel. The y-line was to show how close measurements could be made to the window surface.

RESULTS

Past measurements of the flow in the LCC showed the data rate, when measuring through the windows, could vary strongly from point to point. Data rate always dropped to zero as the edges of the windows were approached, and certain "dead zones" could be found across the window. Low data rate not only increases the time needed to acquire measurements, but also limits the ability to acquire velocity spectra. Thus, the first measure of window performance was the measured data rate through the windows.

If diffraction of the beams occurs when passing through the windows, it will negatively impact the accuracy of the measurements. This effect has not previously been quantified, since there was no standard with which to compare the measurements. Therefore, a second measure of window performance was the measured velocity.

Data Rate

Data rate when measuring through the windows is shown in Figure 1. Also shown in the top part of the figure are the locations of the other surveys — the y-plane and the y-line. Distances are from the tunnel

centerline and are normalized by the channel height, *h*. The data rate is normalized by the reference data rate. Data rate through both windows drops off as the measurement location gets farther from the window ($y/h = 0.5$), most likely due to the absorption and scattering of light in the water. Data rate very near the window is poor for the acrylic, but not for the glass. Slightly farther from the window, data rate is good for either window. Towards the center of the channel, $y/h = 0$, several locations appear in the acrylic window with near zero data rate. This does not occur in the glass.

Figure 2 shows the data rate for the axial component measured in 2001. In this data, the window number was not recorded. However, it can be seen that the performance of this window is substantially worse than window number 20 which was used for the present tests. The data rate is very low for much of the lower portion of the window.

The data rate in a plane parallel to the window, 600 mm from the tunnel center, is shown in Figure 3. The data rate through the glass window is generally uniform, and better than that through the acrylic. Most notably, the data rate drops off near the edge of the acrylic window. As the location approaches the edge of the acrylic window, measurements become impossible. If the measurement plane had been closer to the tunnel centerline, the situation with the acrylic would have been much worse. Unfortunately, those measurements were not performed in this limited test.

Also shown is the data rate in a line approaching the window in Figure 4. In this figure, it can be seen that measurements could be made to about 40 mm from the wall with the acrylic window, and to about 22 mm from the wall with the glass window. This is most likely due to the better surface finish of the glass, but might also be due to the better clarity of the glass.

Accuracy

The measured axial component of velocity in the *x*-plane is shown for both the glass and the acrylic windows in Figure 5. The plots are generally similar. However, small variations in the magnitude of the measured velocity are apparent in the measurements through the acrylic window. These fluctuations, on the order of 0.5 – 1%, do not appear in the glass window, and do not make physical sense. The same fluctuations were also seen on a repeated measurement, and so are not an artifact of the normalization. It is apparent that the source of these measured fluctuations is the window itself.

Shown in Figure 6 is the measured axial velocity in the *y*-plane. The velocity measured in the center portion of the window is similar for the glass and acrylic. However, the acrylic shows a decrease in the measured velocity near the edges of the window. This is better illustrated in Figure 7, which shows a horizontal line of measurements across the center of the window. With the glass window, the measurements are constant across

the window. With the acrylic, the measured velocity drops by 2 – 3% near the window edge. The effect would be, again, more pronounced near the center of the channel, farther from the window surface.

In addition, though not documented in these tests, there is some evidence that changing pressure in the channel leads to a change in the measured velocity. This would presumably come through small deformations in the window. Since the glass is far stiffer than the acrylic, the effect should be largely eliminated with glass windows.

The earlier measurements of Park et al.[1] showed some small variations in the vertical velocity which were presumed to be due to the channel secondary flow, but which could conceivably been due to biasing of the measurements by the window. The measured vertical velocity, *W*, is shown in Figure 8 for both the acrylic and glass windows. The flow is seen to be sweeping down near the window and sweeping up approximately a quarter of the distance into the channel. This is not only consistent across window types, but is also consistent with the flow measured in 2001 by Park.

CONCLUSIONS AND RECOMMENDATIONS

The measurements help quantify some of the limitations of using the acrylic windows in the LCC for use with LDV. If the best acrylic windows are used, measurements are made away from the edges of the window, and the measurements are not too far from the window, the acrylic windows work reasonably well. However, even with the best acrylic window, there are significant regions of the flow in which the LDV measurements have problems. In general, the data rate drops to very low levels near the window edges, and there are regions across the window at which measurements can not be made. In addition, variations in the measured velocity are seen when measuring through the acrylic windows which are clearly not a part of the flowfield. Thus measuring through the acrylic windows results in decreased accuracy. The results would probably have been more pronounced had a y-plane of measurements been made near the tunnel centerline. These limitations are not present when measuring through the glass windows.

Use of the glass windows for future LDV measurements will result in the following benefits:

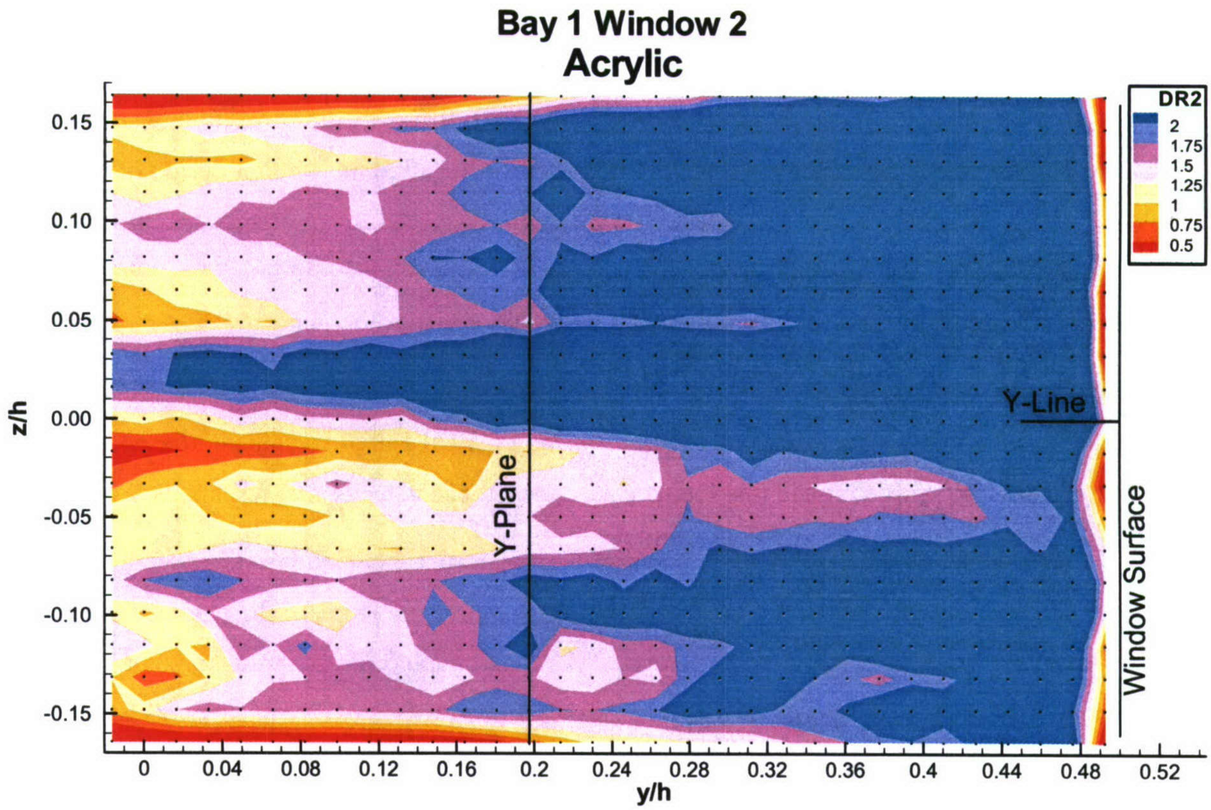
1. **Increased access to the flowfield.** With the glass windows, measurements can be made right up to the edge of the window. Also, measurements can be made closer to the window surface. The "dead zones" in the flowfield, which are more pronounced the further the measurements are into the channel, will be eliminated.
2. **Increased measurement accuracy and decreased measurement uncertainty.** The non-uniformities in the window surface and in the window material cause diffraction of the beams passing through the acrylic windows. This distorts the measurement volume, and results in a change in the measured velocity. The

effect varies across the window area, and can not be corrected. The uncertainty in the measurements is therefore significantly increased. Past statements of the measurement accuracy have overlooked this effect.

3. **Decreased time to obtain measurements and increased capability to make spectral measurements.** The increased data rate over much of the flow allows data to be acquired in a shorter period of time, and less setup time to be used in order to work around the dead regions of the flow. If velocity spectra measurements are to be made, the increased data rate directly leads to increased frequency bandwidth of the spectra. With the acrylic windows, spectra measurements are impossible in many areas of the flow.

With these benefits in mind, I would recommend that all future LDV measurements be made with the glass windows. In addition, because of the effects on accuracy of the LDV measurements due to the measurement through the windows, I would recommend that the way we do reference velocity measurements be changed.

Presently, reference velocity measurements are made through an acrylic window. The acrylic window compromises the accuracy of the measurement. I would recommend that we replace the bay 1a window with an aluminum blank which would have three glass "portholes" for making the reference measurements. This could be manufactured at much lower cost than entire glass window. Round windows 8" in diameter and 1.5" thick are available off-the-shelf for less than $2000 each. Some machining to the glass would be needed so that it could be mounted and sealed, but this would be straight forward. Designing and fabricating the mounting for the windows would also be relatively simple. With this change, reference velocity could still be measured above, below, or at the center of the channel horizontal as needed, but with decreased uncertainty.



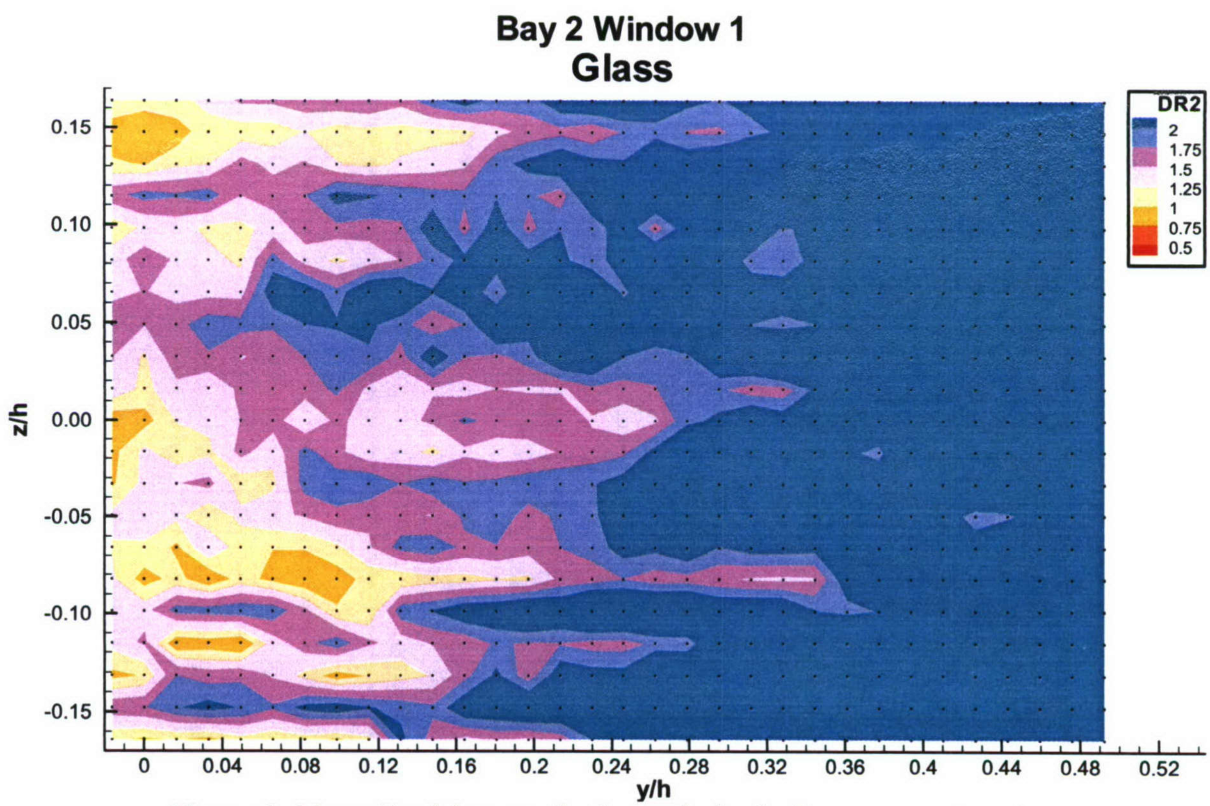


Figure 1. Normalized data rate for the vertical velocity component, x-plane.

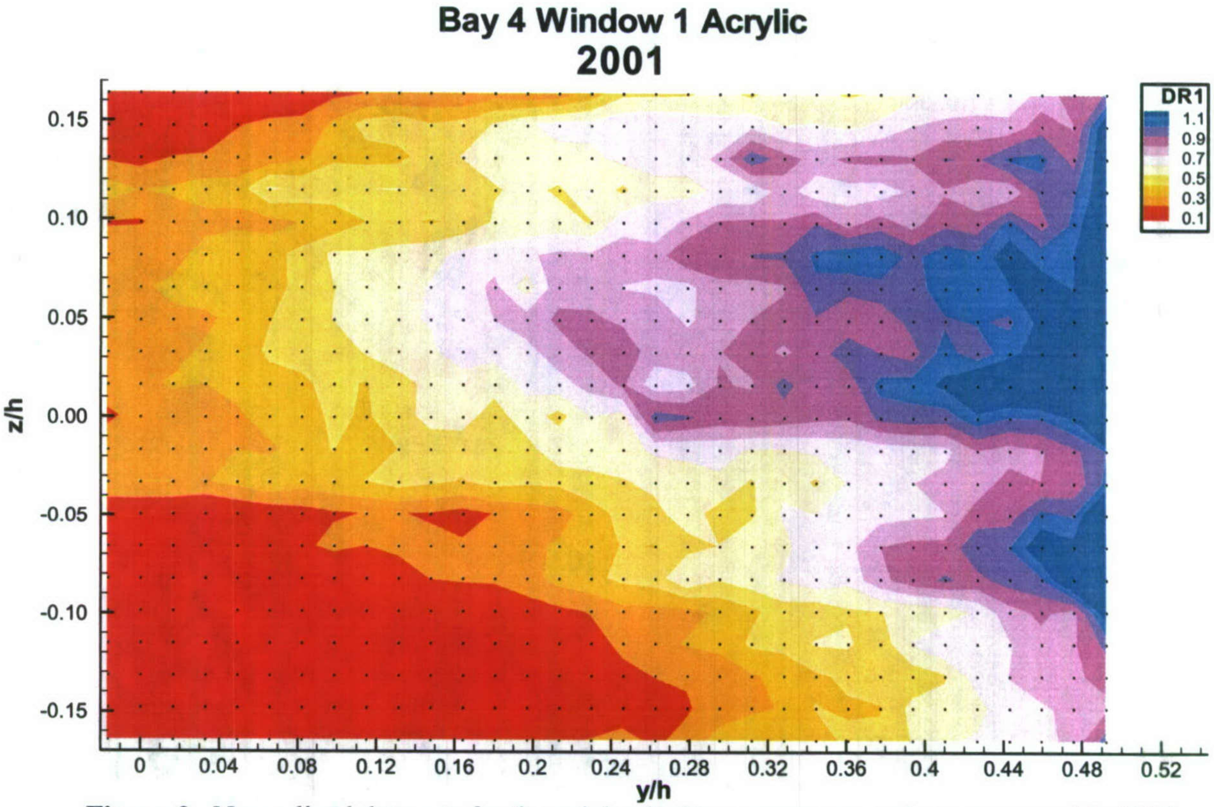


Figure 2. Normalized data rate for the axial velocity component, x-plane, measured in 2001.

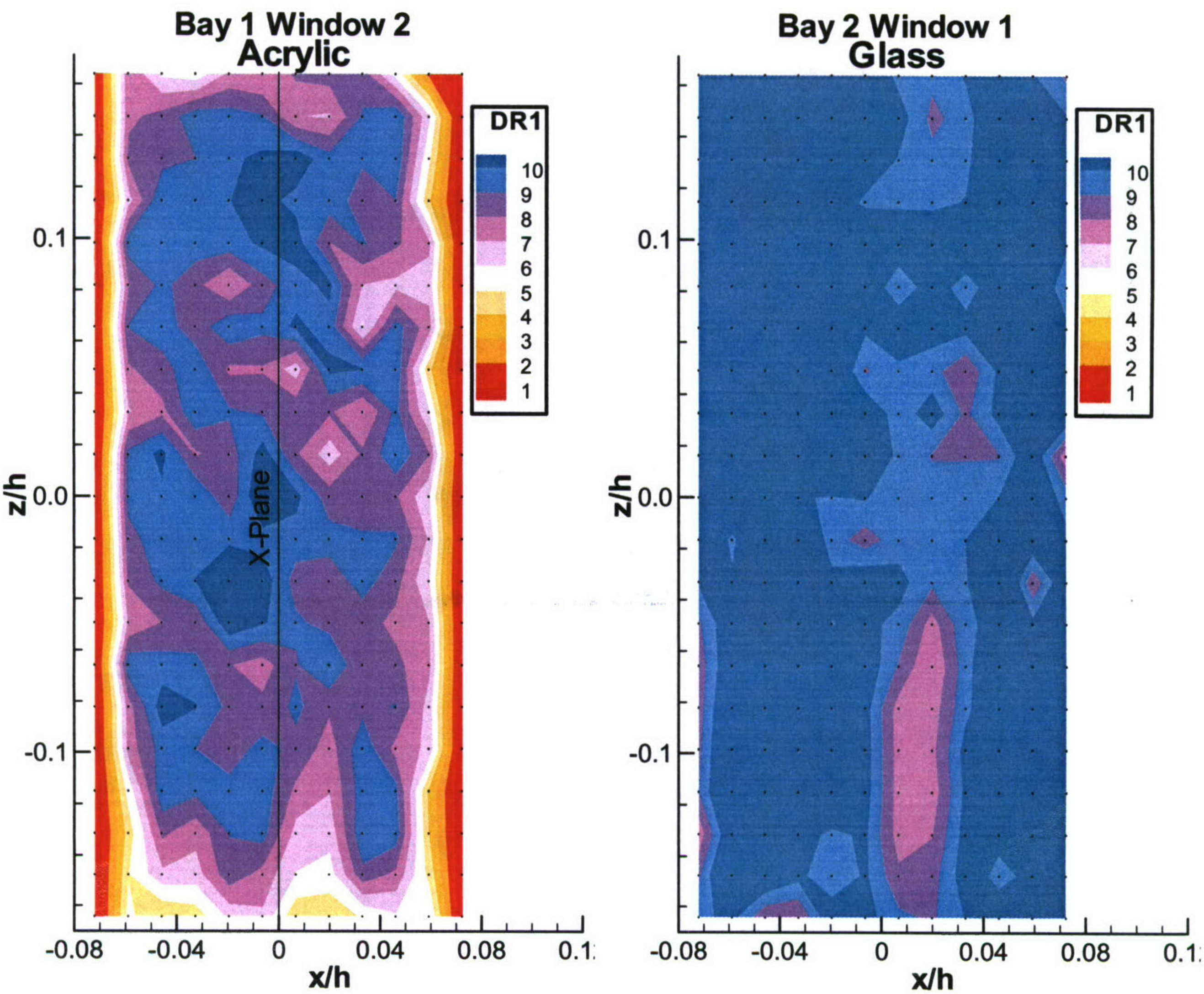


Figure 3. Normalized data rate for the axial velocity component, y-plane.

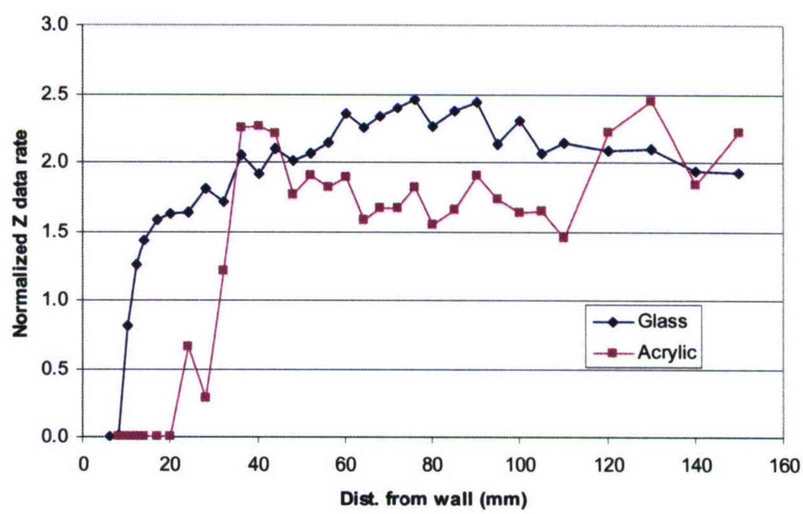


Figure 4. Normalized data rate for the axial velocity component, y-line.

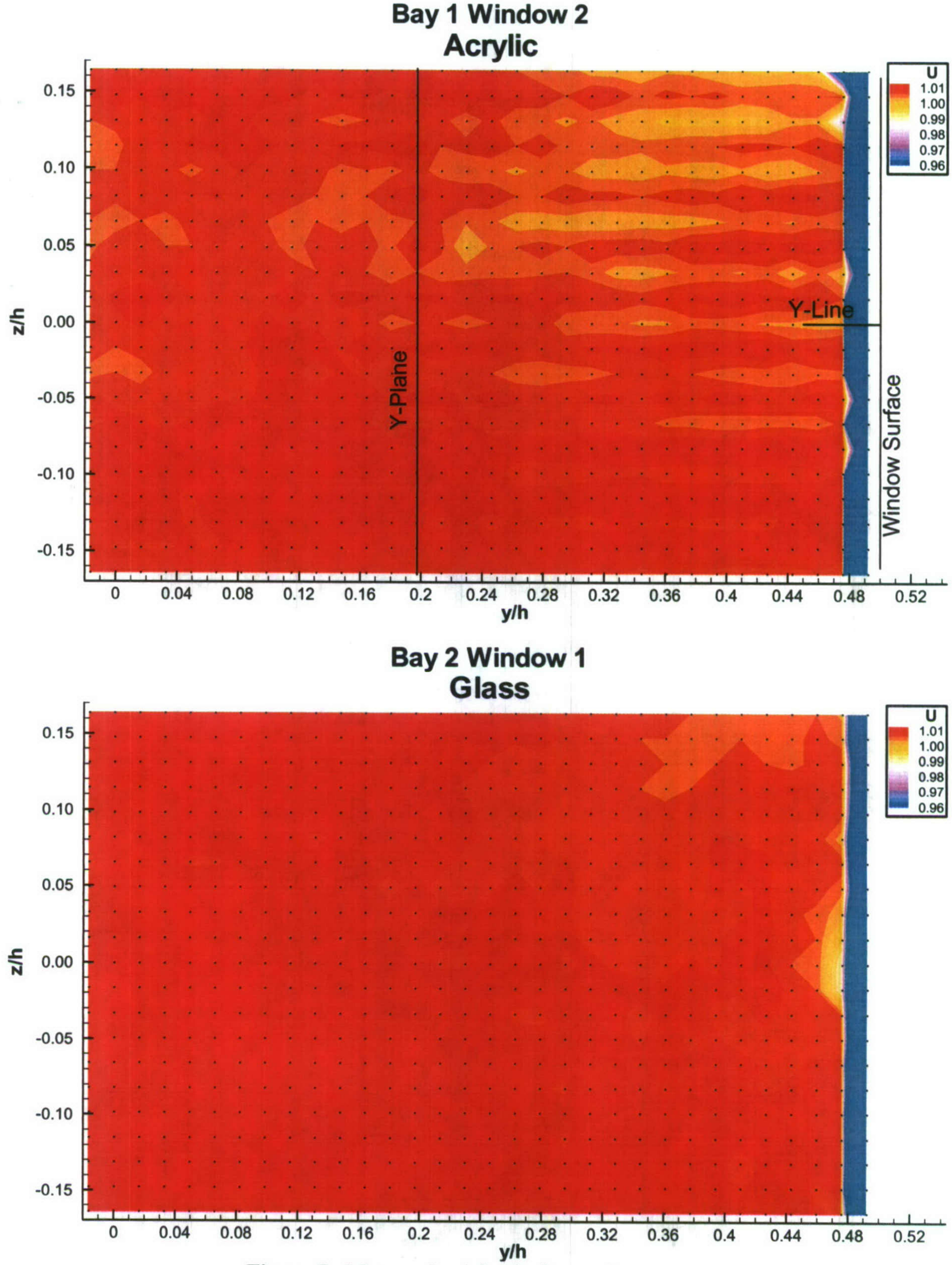


Figure 5. Measured axial velocity, x-plane.

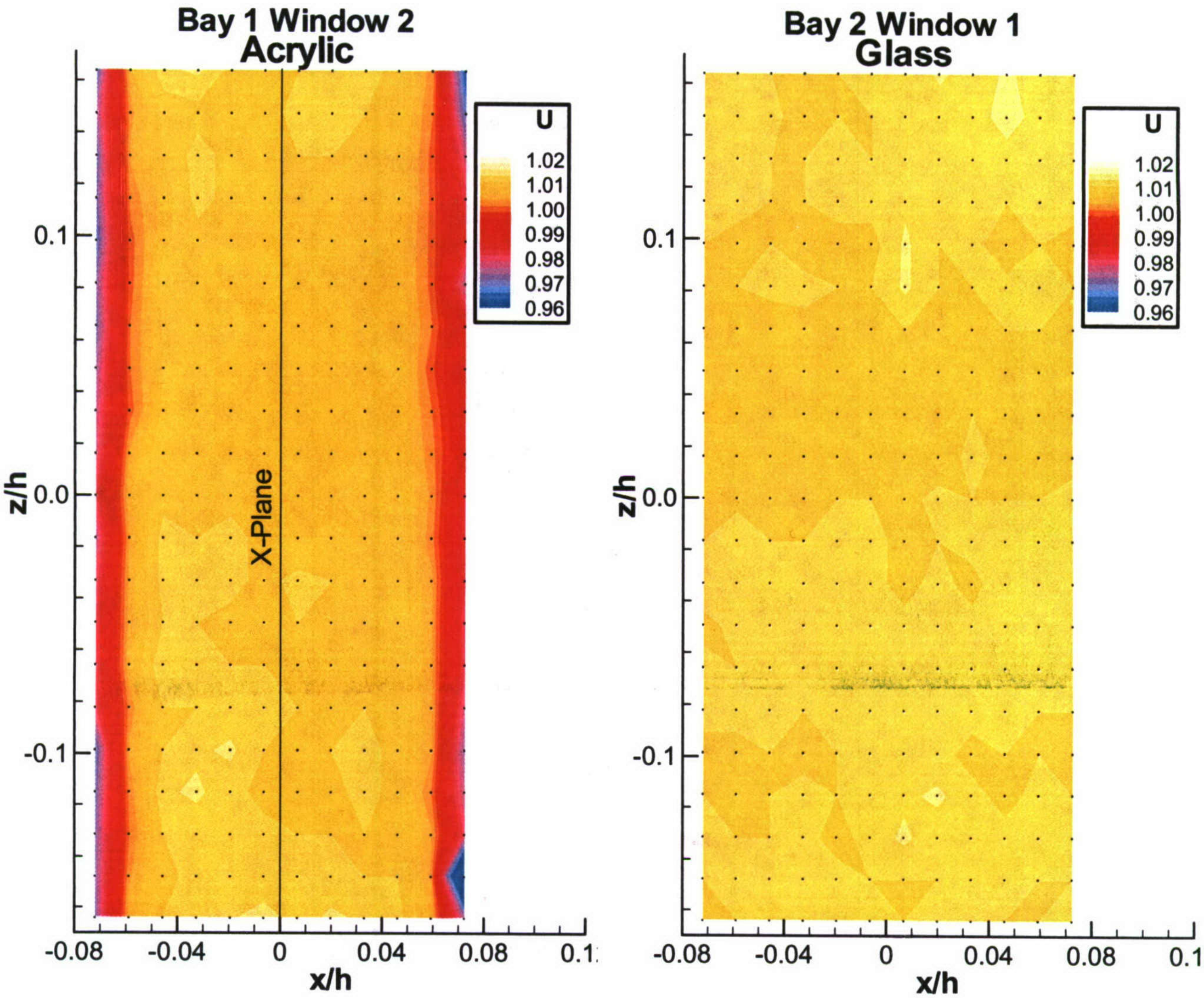


Figure 6. Measured axial velocity, y-plane.

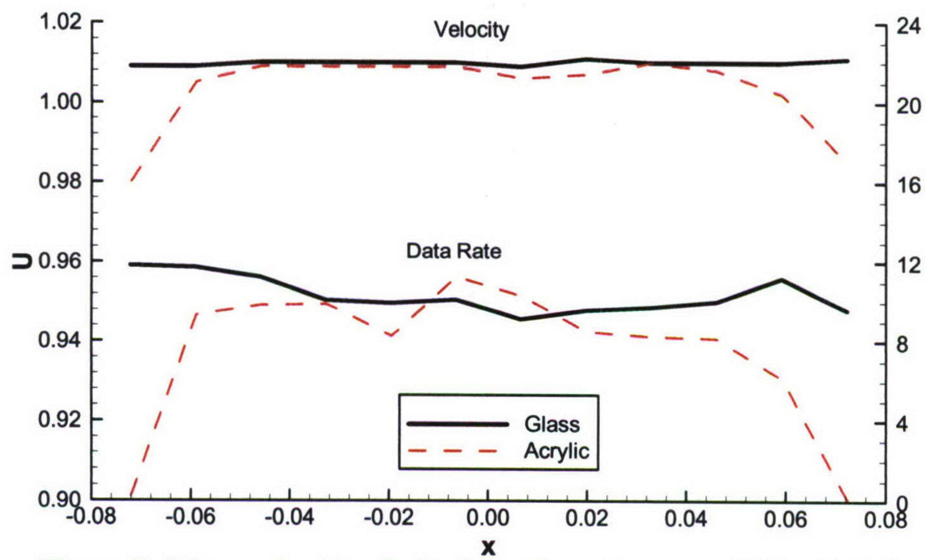
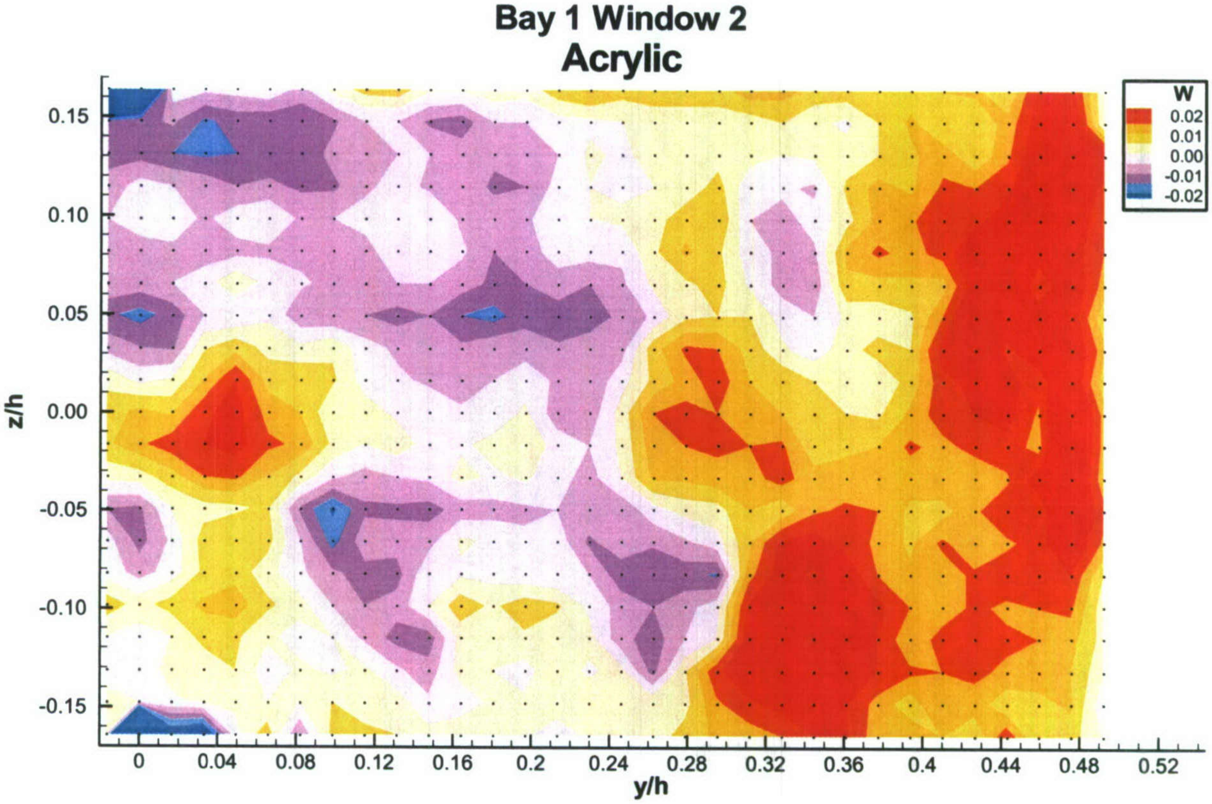


Figure 7. Measured axial velocity from Figure 6, across middle of window.



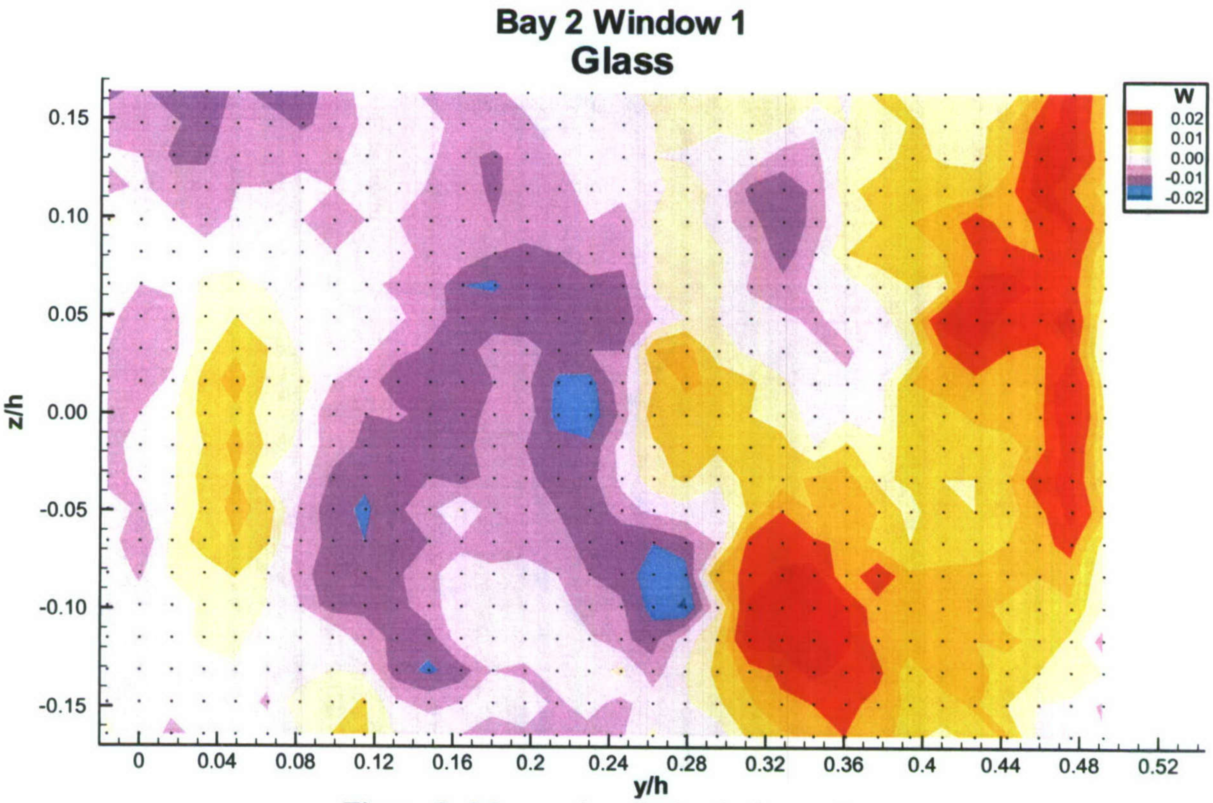


Figure 8. Measured vertical velocity, x-plane.

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[1] Park, J. T., Cutbirth, J. M., and Brewer, W. H., "Hydrodynamic Performance of the Large Cavitation Channel (LCC)," NSWCCD-50-TR-2002/068, Naval Surface Warfare Center, Carderock Division, December 2002.

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